Dose Requirement for the LENA Instrument on IMAGE

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Executive Summary

The initial top level dose requirement (Level 1) set for the IMAGE/LENA instrument electronics was 30 $krads_{al}$ for the 2-year mission. A more in-depth analysis of the shielding and geometry of the LENA electronics box enclosure and IMAGE spacecraft skin has shown that a more realistic dose requirement (Level 2) is 11.4 $krads_{si}$. This estimate uses the same environment for the trapped particle fluences that was used for the 30 $krads_{al}$ estimate but uses a more severe solar proton environment. A total of 200 mils of available aluminum shielding was assumed. The 200 mils of shielding is represented in the model as: 4_ coverage of 20 mils of aluminum in a rectangular configuration representing the spacecraft skin and 4_ coverage of 180 mils of aluminum representing a rectangular electronics box enclosure. The 11.4 $krads_{si}$ value does not include a design margin. Attachment A describes Level 1 and Level 2 dose estimates.

Report

At the request of the IMAGE/LENA project, the Radiation Physics Office (RPO) reviewed the project's initial dose requirement specification. The 30 $krads_{al}$ specification was a Level 1 (top level) requirement derived from dose-depth curves. This requirement was reviewed and a Level 2 requirement was calculated as described below. Attachment A describes Level 1 and Level 2 requirements.

Initial Spreadsheet Calculations

The existing radiation environment definition and dose specifications were obtained from John Laudadio in the form of an EXCEL spreadsheet. The spreadsheet contained the predicted fluences and doses for 2-year IMAGE mission. The particle fluence spectra for trapped protons and electrons and protons from solar events were given external to the spacecraft. Labeling on the spreadsheet indicated that NASA's AE-8 and AP-8 models were used to calculate the trapped particle spectra. The model used to calculate the solar proton spectra was not given. The fluence spectra were then converted to doses behind aluminum shields generating "dose-depth curves". The spreadsheet does not document which method was used to calculate the doses.

Trapped Particle Environment

The spreadsheet environment for trapped particles was compared to an environment generated by the RPO using NASA's standard AP-8 and AE-8 models and reasonable agreement was found with the RPO environments being lower. The probable explanation is that the RPO calculated fluence was averaged over the long-term precession of the argument of perigee,[*] whereas, the spreadsheet values were most likely for a worst case argument of perigee.

Solar Proton Environment

[*] As the latitude of perigee moves toward the equator, the spacecraft spends less t trapped radiation belts, reducing the proton and electron exposure.

The mission is scheduled to fly during the active phase of the solar cycle, greatly increasing the likelihood that solar events will occur. The solar events increase the levels of electrons, protons and other heavy ions in interplanetary space. The additional protons and heavy ions increase the rate of occurrence of single event effects during solar events, but only the protons are a factor in total dose accumulation. Unfortunately, a solar proton model that includes the data from the severe Solar Cycle 22 is not yet available.

The spreadsheet does not indicate what model or what parameters were used to determine the number of extremely large solar proton events, only that 2 events were predicted for the 2-year mission. Because 3 extremely large events occurred within a one month period in September - October 1989, the RPO recommends that 3 extremely large events be used for a 2-year mission.

Level 1 Requirement - Dose-Depth Curves

It is not known what method was used to calculate the dose-depth curves from the particle fluences. Also, note that the dose units are in $rads_{al}$. Considering that most parts are silicon based, a more appropriate unit is $rads_{si}$. In order to verify the Level 1 requirement set by the project, the particle fluences from the spreadsheet were used to calculate dose-depth curves using adjoint Monte Carlo transport methods. The figure below compares the dose-depth curves from the spreadsheet to the results of the Monte Carlo calculation, showing that the Monte Carlo results (in units of $rads_{si}$) are slightly lower. By checking the two top curves (dose for solid aluminum spheres), one can see that the total dose is approximately 30 $krads_{si}$ for 200 mils of aluminum shielding. This defines the Level 1 requirement. Note that this dose value does not include the commonly recommended “factor of 2” design margin.

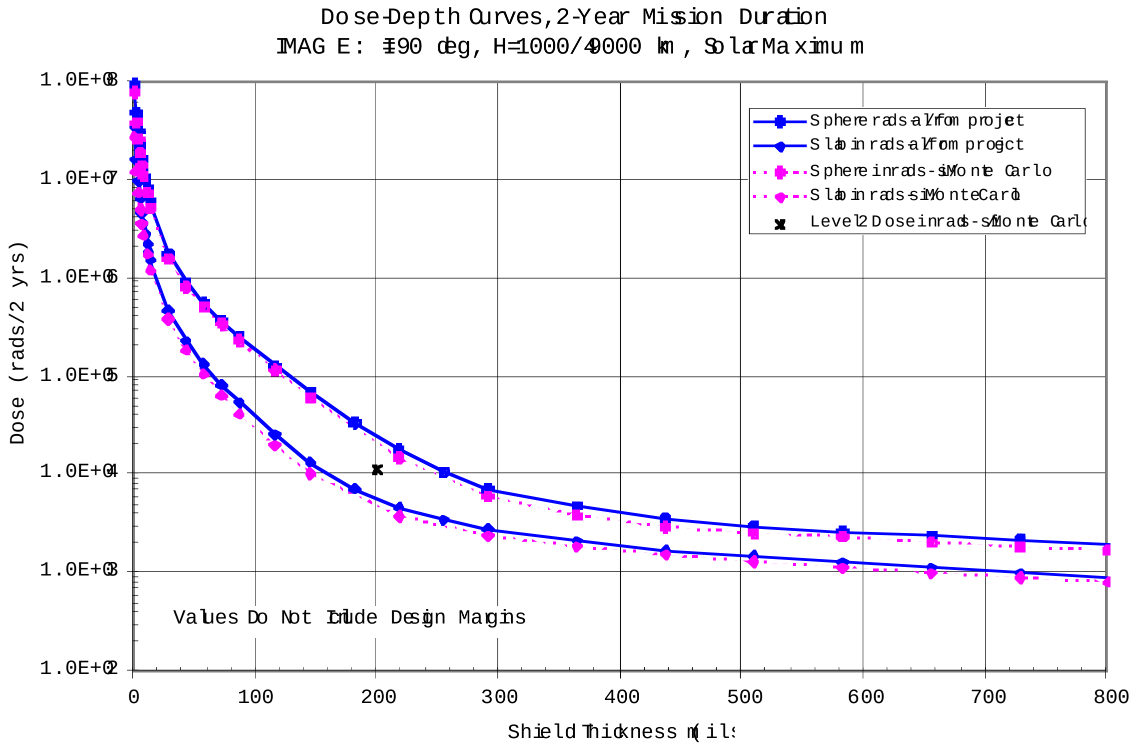
Level 2 Requirement - Box Specification

Part testing for the LENA instrument has shown that some of the parts fail to meet the 30 $krads_{si}$ requirement. Therefore, the RPO developed a simple box model of the LENA electronics box with 180 mil aluminum walls surrounded by a spacecraft skin of 20 mils of aluminum in a rectangular configuration. The model did not include cards, mounting brackets, etc. The trapped and solar particles were transported through the more realistic geometry model using the same Monte Carlo technique, obtaining a more accurate dose prediction. These dose predictions are given in the table below.

Level 2 Dose Requirement
IMAGE/LENA - 2-Year Mission
Values Do Not Contain Design Margin

Dose Source	Dose ($krads_{si}$)
Trapped Protons	3.73
Trapped Electrons	2.39
Bremsstrahlung Photons	0.39
3 Solar Proton Events	4.86
Total	11.37

The table shows that, even when increasing the number of solar proton events to 3, the more realistic model predicts only 11.37 $krads_{si}$ for the 2-year mission. When this total dose prediction is entered on the figure below at 200 mils of shielding, it can be seen that the Level 2 prediction falls between the 2 x slab and solid sphere predictions as expected.


Dose-Depth Curves, 2-Year Mission Duration
IMAGE: i=90 deg, H=1000/49000 km, Solar Maximum
Dose (rads/2 yrs)
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
Sphere rads-al from project
Slab in rads-al from project
Sphere in rads-si Monte Carlo
Slab in rads-si Monte Carlo
Level 2 Dose in rads-si Monte Carlo
Values Do Not Include Design Margins
0
100
200
300
400
500
600
700
800
Shield Thickness (mils)

Attachment A

The Radiation Physics Office specifies total dose requirements at three levels:

Level 1 - Top Level Requirement

Level 1 is a top level requirement, and as such, is the requirement usually set in Phase A of a program after the orbit is selected. These requirements are set by defining the radiation environment external to the spacecraft and converting the particle fluences to dose as a function of aluminum shield thicknesses for generic geometries. Typically, two geometries are used: solid aluminum sphere and aluminum slab x 2. The solid sphere geometry forces a dose calculation that always uses the shortest particle path through the material so it is an upper bound estimate. The slab geometry maximizes the particle path through the material making it a lower bound estimate. Dose values for the actual spacecraft structure lie between these theoretical geometries.

Level 2 - Box Level Requirement

As parts lists are "scrubbed" for total dose and single event effects issues, some parts usually fail to qualify for use at the Level 1 requirement. At this point, there are three choices: use an equivalent rad-hard part, use a different part, or refine the Level 1 requirement. With the demise of the rad-hard market and the lag in technology of rad-hard parts, the first choice is increasingly out of the question. The second choice often means redesigning and/or retesting parts. The third choice, refining the dose requirement., is done at Level 2 by defining a box level requirement. A model is made of the electronics box and 4_ satellite skin. The box model typically includes box walls, 4_ satellite skins, and boards with heat sinks and grounding planes. The particle environment is then transported through the model using adjoint Monte Carlo techniques and converted to total dose response. The total dose calculated with this method is lower than the solid sphere estimate because it is for a real geometry. This is a cost effective method of qualifying parts, especially if the box model is kept simple. The added advantages are that particle spectra at locations inside the box are available from the calculations and the effectiveness of spot shielding can be assessed by adding it to the model.

Level 3 - Full Model Requirement

For cases where the mission is in a severe radiation environment and/or a sensitive part must be used, a full model of the spacecraft, boxes, and instruments is developed. The same codes are used to transport the particle environment and calculate total dose. Obtaining a Level 3 requirement is more expensive but, in many cases, the cost is recovered by avoiding part testing, redesigns, and use of rad-hard parts.